AASHTO LRFD Bridge Design Specifications: Combined Shear and Torsion

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Within the context of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*, and as it applies to concrete bridges, elements must be designed for combined shear and torsion. In general terms, there are two broad categories of torsion: St. Venant torsion and warping torsion. In cases governed by St. Venant torsion, there is no distortion within the plane of twisting; however, out-of-plane distortion (that is, warping) is not restrained and does not vary along the length of the structural member under consideration. As the name implies, in cases where there is distortion within the plane of twisting, warping torsion must be considered. Open sections, such as horizontally curved U-beams, are subjected to both forms of torsion. Closed sections that essentially have a "tubular" appearance are primarily subjected to St. Venant torsion. Increased member slenderness, and gradual application of torque (such as that introduced by self-weight of the member) all lead to a greater St. Venant contribution.

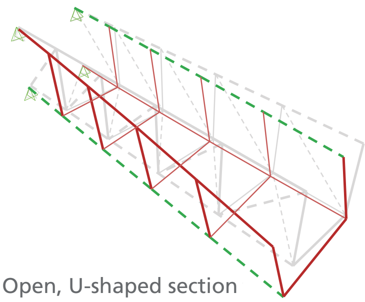
Understanding the displacement/deformation fields associated with both St. Venant and warping torsion enables the structural designer to make the right choices during the analysis stage, such that models conducive to producing the expected deformation patterns can be selected. Whereas some analysis tools consider the aforementioned facts implicitly, others require selection of element types and mesh density that are consistent with the problem at hand.

Another important aspect of design for the combined effects of shear torsion relates to the understanding of torsional cracking and its implications. Upon cracking, the torsional stiffness of a reinforced concrete element reduces drastically. This reduction may be as large as 90%. In cases where the structure is statically indeterminate, redistribution of forces upon torsional cracking is possible when other load paths are present to maintain stability (compatibility torsion; see this column in the Summer 2016 issue of *ASPIRE*SM). In such cases, the redistribution of forces implies that torsional moments applied to a member are released (that is, torque is reduced down to the level of cracking torsion) through the formation of the torsional hinges and the released torsional moments may be converted into additional bending moments and associated shear forces that must be resisted by other elements. This leads to an understanding that structural details, such as the use of well-anchored reinforcing bars, and proper use of crack-control reinforcement are essential to ensure acceptable serviceability of the regions in which torsional cracking is expected.

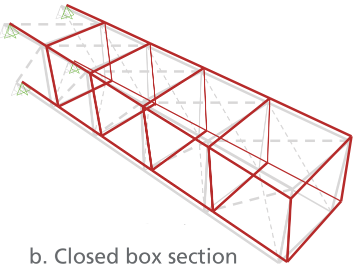
In statically determinate cases and statically indeterminate cases where there is equilibrium torsion, the redistribution of internal forces is not possible and torsional resistance of the element is essential to maintain equilibrium. Based on the fundamental principles of Modified Compression Field Theory, the *AASHTO LRFD Bridge Design Specifications* allow for the calculations of resistance under the combined effects of shear, torsion, and flexure, as discussed in this column in the Spring 2017 issue of *ASPIRE*. AASHTO LRFD provisions for cracking torsion (that is, Eq. 5.7.2.1-4 and 5.7.2.1-5), are based on the "thin-walled tube" analogy and the application of pure torsion. These equations, by definition, do not take into account the warping component of the torsion or other load effects, if present.

We must remember that in cases where significant torsion is introduced abruptly into an element, for open sections subjected to torsion and having a relatively short length, the effects of warping can be significant and should be accounted for.

In cases where combined effects of shear and torsion are present, it is prudent to calculate the principal tensile stress within the webs of the concrete elements under consideration and obtain an estimate for the cracking torsion on that basis. Torsion and shear may have additive stresses causing diagonal tension in one of the webs of a box or U beam, and as such, the combination of these effects may exacerbate diagonal cracking and associated redistribution of internal forces. In short, design for combined shear and torsion requires comprehensive understanding of structural behavior and of the basis of the code expressions.



a. Open, U-shaped section



b. Closed box section

Isolated cantilever beam in pure torsion. Figure: Hossein Yousefpour.